Lecture 2

Barriers to climate action: transitional costs, distributional issues and politics

In my first lecture, I described the technologies which could enable us to build a net zero emissions global economy and as a result limit global warming to a manageable level. And I hope I left those of you who attended lecture 1 in a reasonably optimistic mood since I described how (**Exhibit 1**)

- Clean electrification will enable us to eliminate some 60% of GHG emissions, at no eventual cost to consumer living standards
- We already have technologies to decarbonise the so-called hard to abate – long distance transport and heavy industry – at costs which while important at the business to business level have a very small consumer impact
- The biggest uncertainty relates to food production and its land use implications, but with several solutions potentially available

So that putting it all together, I believe there is still a clear possibility of limiting global warming to below and ideally well below 2°C.

But we are not on a path to achieve that limit.

Scientific analysis suggests that to have a 66% chance of limiting global warming to 2°C, cumulative CO2 emissions from now until the whole world reaches net zero cannot exceed about 1010 Gt, and about 830GT for a 50% probability [1]. (**Exhibit 2**) And if we add up the broad pledges which countries have made to achieve net zero emissions by different dates – 2050 for Europe, 2060 for China, 2070 for India (**Exhibit 3)** , and add an assumption that land use change emissions decline on straight line to zero by 2060 , total possible CO2 emissions of about 860GT might imply a temperature a bit below 2°C, say around 1.9°C in 2100 (**Exhibit 4**)

But if we look instead at the "Stated policies" to which countries are in principle committed , the IEA's best estimate is that we are on a path for 2.5°C warming by the end of the century: while if we look only at "Current Policies" already introduced , close to 3C warming is likely (**Exhibit 5)** .

So why, if most of the technologies to achieve zero carbon economy are achievable – why are we not making faster progress? In this lecture, I will explore some of the economic barriers to the speed of decarbonisation.

But I want to begin with a caveat. Economists in particular, and I suspect there are some of those here this evening , should be wary of assuming that economic reason rules the

[1] www.essd.copernicus.org/articles/17/2641/2025/essd-17-2641-2025.pdf. Note that these relationships between CO2 emissions and temperature depend on the assumptions made about the level of other GHG emissions

world , and must recognise the power of social and political forces , of ideologies and motivations which are not significantly influenced by economic factors.

And over the last four years, we have seen dramatic setbacks to progress towards the Paris climate objectives whose roots have nothing to do with the economics of climate change.

Russia's invasion of Ukraine was driven by a nationalist ideology, by President Putin's belief in a historically determined and almost mystical union of Russia and Ukraine, which is entirely unrelated to the economic effects of climate change, (**Exhibit 6**) but which produced a surge in energy prices which helped foster political forces in Europe which seek to reverse net zero policies[2]. And it created a need for European rearmament which reduces the fiscal space for direct government support for the energy transition.

Donald Trump's election in the US cannot be explained by the costs of achieving an energy transition, but has been a disaster for climate change action, with US clean tech investment falling, big cuts in government support for scientific research into climate change, the elimination of US climate finance to support transition in developing countries, and a commitment to "drill baby drill" . (**Exhibit 7**) Donald Trump doesn't like the look of offshore wind farms, and offshore wind farms have therefore been banned. The world has to find ways of limiting climate change despite that depressing reality.

And public debates about climate change are now conducted in a media environment radically changed even over the 10 years since the Paris climate agreement. Social media algorithms deliberately foster extreme belief systems – including both climate change denial and exaggerated beliefs in an immediate and total climate catastrophe if we don't "just stop oil" tomorrow .

Disinformation is rife, and different policy issues are entangled in ways which we may think irrational, but which still create huge challenges for climate change action. At an Energy Transitions Commission meeting in 2024, our members were startled by a presentation from an external expert which showed how, in parts of social media, manosphere opposition to suppose woke feminism, anti- vax sentiment and climate change denial, coalesce into a world view in which a liberal elite is determined to destroy traditional culture and masculinity, and through a "climate lockdown" take away people's cars, forcing them into 15 minute cities where only cycling and walking are allowed. (**Exhibit 8)**[3]

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[2] Vladimir Putin , *On the historical unity of Russians and Ukrainians* http://www.en.kremlin.ru/events/president/news/66181

[3] https://misinforeview.hks.harvard.edu/article/the-climate-lockdown-conspiracy-you-cant-fact-check-possibility/

We have to win the argument for climate change action in this changed context – and carefully explaining what rational economic analysis tells us will not be sufficient.

But if economics is not everything it is still important. And the economic consequences of the energy transition will foster opposition to climate change action if we do not anticipate and manage them.

In this lecture I will therefore focus on four specific aspects of the economics of the transition which have implications for the policies required to achieve a well below 2°C temperature limit, policies which I will then discuss in Lecture 3 .

These aspects are:

- The investment costs of achieving net zero emissions.
- The cost of reducing emissions faster than along a lowest cost pathway
- Distributional effects on people's incomes, jobs and the costs they face
- And China – the opportunity and a challenge

Investment costs of achieving a net zero emissions economy.

In Lecture 1 I argued that once we have achieved a zero emissions economy, the impact on the living stands of people then alive– compared to a counterfactual in which we continue to rely on fossil fuels – will either be so small as to be unnoticed, or positive, with massive clean electrification delivering energy services and products at lower costs than would otherwise be the case.

But that doesn't mean that the transition is costless – because that optimistic future can only be achieved with significant investment, and increased investment must, in most economic conditions, imply some decrease in current personal consumption.

Exhibit 9 shows two newspaper headlines, taken from The Times and the Financial Times on the same day, December 11th 2025, which refer to the same report from the UK National Electricity System Operator, which assesses the economic consequences of the UK building a zero carbon electricity system between now and 2050[4].

The Financial Times reported "*UK energy costs likely to halve by 2050*" ; The Times reported that achieving net zero would cost households £500 per annum from now to 2050.[5]

Both headlines reflected the newspapers broad editorial position – the Financial Times clearly committed to the net zero target, and The Times increasingly arguing against.

But in broad direction both headlines are simultaneously right:

- By 2050 UK consumers are very likely to enjoy significantly lower total energy costs than today; electricity prices will almost certainly be lower but total

[4] *https://www.ft.com/content/25ad418f-6961-417b-825e-2071c1e693f2*
[5] https://www.thetimes.com/uk/politics/article/britain-net-zero-target-zxsppp998

electricity bills higher because of greatly increased electricity use ; but that extra expenditure on electricity will be than offset by the disappearance of gas bills and of expenditure on road transport fuel.
- But there is an initial investment cost of getting there, and if that investment cost is recovered from electricity users over the next 25 years, some transitional increase in electricity prices will occur.

Any major technology transition entails investment to achieve future benefits. But in the case of the required energy transition, this effect is accentuated by the inherent cost structure of the relevant electric technologies, with large upfront costs both in electricity generation equipment (whether renewable or nuclear) and in electricity using equipment, to provide us with a capital assets which can then manipulate photons, electrons, ions and magnetic fields at low and even zero marginal cost.

Estimating the total net investment required entails some tricky measurement and conceptual issues. Future investment cost will depend on future cost trends in key technologies which are inherently uncertain. And it is vital, particularly in developing countries, to distinguish the gross investment costs of building much larger electricity systems, from the smaller net cost of the energy transition, since large increases in electricity supply would be required to support economic development whether or not there were a climate change imperative

But **Exhibit 10** set out the estimates that ETC made in our report on *Financing the transition* published in 2023[6]. We projected then that from a base of around $1 trillion global investments in clean energy in 2020, we needed to reach about $2 trillion by 2025 and $3tr by 2030, reaching a peak of around $4.5 trillion per annum in the 2040s, before declining slowly thereafter. This increased gross investment would be partially offset by reduced fossil fuel investment, declining from $1 trillion in the early 2020 to $Xtr by 2030 and $Y tr by mid century.

The exhibit also illustrates the sectoral composition of the required investment.

- With 70% of all the investment arising from the need to build larger and fully decarbonised electricity systems, through investment in both generation and grids.
- With another 20% of investment in building structures and equipment , including for instance investment in improved insulation and the installation of heat pumps for building heating.
- And with all the other investment categories – investment in new iron making plants and cement kilns, new ships, and battery and solar PV factories, actually quite a small % of the total, though of course significant for individual companies assessing whether there is a business case for making the investment.

[6] https://www.energy-transitions.org/publications/financing-the-transition-etc/

So if this is the broad scale of the investment needed for the energy transition, what is actually happening, and how difficult it will be to achieve the further increases still required? Four observations are important:

- First that at the global aggregate level investment has actually risen broadly in line with what we projected would be required. (**Exhibit 11**) The IEA estimates that clean energy investment has increased from $1.2tr in 2020 to $2.1tr in 2025, with big increases in renewable power investment, a significant but somewhat smaller growth in grid investments, and a large increase in energy efficiency equipment investment, in particular in buildings[7]. And in volume terms the increase is even more significant, since the falling price of clean tech equipment, in particular solar PV and batteries, is enabling countries across the world to get more "bang for their buck"
- Second however the investment is heavily skewed towards the developed countries and China. In the ETC's 2023 report, we suggested that the biggest increase would need to occur in upper middle and middle income countries, with their annual investments potentially reaching $900bn per annum in the late 2020s, an increase of four times from their 2021 levels versus a required increase of two times in China and developed countries. (**Exhibit 12**) But the IEA 2025 figures show that while China and the advanced economies have increased investment broadly in line with our projection , investment in middle lower income economies in Latin America , Southeast Asia, the Middle East, and Africa lags far behind (**Exhibit 13**)[8] . We are not seeing in those regions anything like the growth of clean investment required to put us on a path to limit global warming to well below 2°C.
- Third, the investment still required is not daunting when considered as a percentage of global GDP. $2 trillion of investment today is about 1.7% of global GDP, and given reasonable projections for global GDP growth, $4.5tr per annum in the 2040s could be ~2.5% of global GDP at that time[9]. We therefore need to further increase the percentage of global GDP invested in the energy transition by about 0.8% of GDP over the next 20 years. These percentages compare with overall global savings and investment of around 26% of global GDP [10], and are a similar order of magnitude to the investment levels seen in previous waves of

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[7] IEA World Energy Investment 2025 . https://www.iea.org/reports/world-energy-investment-2025/executive-summary

[8] High US investments in 2025 reflect big increases between 2022 -25 in response to the various forms of subsidy introduced by the Biden administration Inflation Reduction Act; looking forward a significant reduction is likely

[9] Global GDP in 2025 was #$117tr on Market Exchange Rate basis , which is the relevant comparator since IEA investment estimates are also done on an MER basis . If the global economy achieved 2.5% GDP growth from now to 2045 , global GDP would reach ~$ 190bn

[10] https://data.imf.org/en/Data-Explorer

transformational technology investment: in the 1870s and 1880s, the US invested about 2 - 2.5% of GDP in railway construction[11].

- But fourth, the fact that the % of GDP is small, does not mean that the additional cost to consumers can be ignored or will be easily accepted. **Exhibit 14** presents estimates by the UK CCC of the additional investment needed to achieve the UK's commitment to net zero emissions by 2050, with large increases in electricity supply and buildings (insulation and heat pumps) for the next two decades, though with power system investment falling off in the 2040s, and with surface transport capital expenditure (i.e buying cars and trucks) actually lower in the 2040s than under a business as usual scenario.
  - By 2050, UK investment in energy producing and using equipment will start falling below what it would be in a fossil fuel dominated energy based system, but between now and 2030, investment has to rise by around a further 0.9% of GDP.[12]
  - Gradually over time , this will be offset by operating cost savings, with net savings (annual capex minus opex) after 2040. (**Exhibit 15**) But during the transition there are costs to be borne .

The right hand side of Exhibit 15 says that the Financial Times headline is justified ; the left hand side that The Times also has a point.

Investment , growth and the cost of capital

There are of course, as John Maynard Keynes most notably demonstrated, specific conditions in which that increased investment might be close to costless . In particular if an economy is suffering from low growth and has significant underemployed capacity because of a deficiency in nominal demand, policies which drive an increase in the investment level could result in such a significant and rapid stimulus to growth that any adverse impact on personal consumption is small and rapidly reversed, with consumption soon higher than it would otherwise have been.

And from the global financial crisis of 2008 until 2020, there was a reasonable case for arguing that the world economy was trapped in precisely those conditions. Short-term policy rates were stuck at the "zero lower bound" as central bankers struggled to prevent inflation falling significantly below targets. And long-term interest rates fell to historically low levels, with real long-term yields significantly negative (**Exhibit 16**).

Convincing analysis suggested that this in part reflected a deficiency of ex-ante desired private investment relative to ex ante -attempted saving[13]: and the world seemed to face a "secular stagnation" challenge in which the need to invest significantly in the

[11] Robert E Gallman and Paul W Rhode , Capital in the nineteenth Century , https://www.nber.org/books-and-chapters/capital-nineteenth-century

[12] UK in 2025 was ~£2900 and at 1.5% growth p.a. would reach £3100bn in 2030. £45bn investment in 2030 is therefore around 1.5% of GDP up from 0.6% in 2025

[13] www.bankofengland.co.uk/-/media/boe/files/working-paper/2015/secular-drivers-of-the-global-real-interest-rate.pdf

energy transition was not so much a challenge as a fortuitous opportunity to stimulate global growth[14].

But the last five years have seen dramatic changes in the macroeconomic context. Nominal yields to maturity of UK 10 year gilts have increased from close to zero in late 2021 to over 4% today , and real yields have increased from minus 1% to around +1.5%. Significant investment in artificial intelligence has meanwhile emerged as a major source of demand for funds, and government fiscal positions are challenged by increasing defence expenditure needs, increasing prospective government debt issue.

The rise in the cost of capital has in turn driven significant increases in the estimated levelised cost of renewable electricity, and particularly so in offshore wind outside China. In the UK's AR4 offshore wind auction round in 2021-22 , winning bidders committed to deliver electricity at £53 per MWH (in 2024 real terms) ; in the just completed AR7 auction round the accepted bids were for £91 per MWH (**Exhibit 17)**

Given these conditions, it is inevitable that increased investment must be to a degree at the expense of reduced consumption , though with multiple ways in which that reduction could be distributed over time and between people . Thus for instance,

- If the installation of heat pumps in residential homes in high latitude countries (or of more efficient air-conditioning in the global sunbelt) is paid for out of household current income or with short-term loans, other categories of household expenditure will fall: but if it is financed via low cost long-term loans, for instance from the government or a domestic development bank, , the consumer expenditure reduction will be spread over time and across a wider set of taxpayers and government bond buyers.

- And if large transmission and distribution grid investments made in advance of an expected increase in electricity demand, are immediately recouped from electricity bills via regulated charges, there is a danger that increased electricity prices will slow the pace of electrification. But if the investments are funded via government borrowing, or the borrowing of domestic development banks, the consumption impact will be spread across a broad array of investors/consumers.

Choices relating to how required investments are financed, and in particular to the potential use of any available public balance sheet capacity, are therefore crucial both because they spread consumption effects over time and between different individuals, and because they can change the effective cost of capital

- Within limits, governments can borrow money at lower cost than the private sector and can leverage this ability to support initial investments either directly, or via public domestic development banks such as the European Investment

[14] www.brookings.edu/wp-content/uploads/2019/03/RachelSummers_web.pdf

Bank , KfW Germany, or BNG in the Netherlands. But they can also through good and consistent policy design reduce the risks facing private investors and therefore the cost of capital for privately funded investments.

- And internationally, multilateral development banks can mobilise international capital flows at costs of capital significantly below the private sector rate, and thus play a crucial role in enabling lowe income countries with high costs of private capital to seize the opportunity created by the falling costs of clean technology capital assets.

The essential point is indeed simple. The deeply electrified energy system of the future is characterised by very low and in some cases zero marginal cost of operation, but with significant upfront capital investment required. The cost of capital for investment is therefore one of the most important drivers of the economics of the transition, and of the distributional impact of the transition within and between countries to which I will turn later.

The costs of going fast enough.

The second economic challenge is the cost of decarbonising fast enough to limit global warming to an acceptable level.

In Lecture 1 I set out an optimistic vision of the future deeply electrified economy which we can achieve. And I'm absolutely certain that by 2100 we will be there. By 2100, and likely several decades earlier, road transport will be almost entirely electric, because EVs are based on a vastly superior and more efficient technology for converting energy into motion : in 2100 internal combustion engines will be seen only at vintage car rallies.

Both commercial and residential buildings will be completely electrified, and most will be equipped with sophisticated electricity management systems and decentralised storage, enabling optimal interface with power systems dominated by intermittent supply. Not only ambient space heating, but most industrial heat will be produced from electricity. Fossil fuel electricity generation will be almost entirely eliminated: next to no coal will be used anywhere in the world, oil demand will be a fraction of the current level, and mainly used to produce plastics rather than to provide energy.

The end point is clear: and we would get there by 2100 as a result of technological progress even if we were unconcerned about climate change and therefore had no policies to ensure rapid progress.

But if the endpoint is clear: the speed of transition is uncertain, and the IEA suggests that given existing stated policies , we are currently on a pathway likely to result in global warming of ~ 2.5°C by 2100 , with hugely adverse impacts on human welfare.

That is also roughly the temperature (2.6C) which Bloomberg New Energy Finance (BNEF) estimates might result from an Economic Transition Scenario, which assesses how future energy systems might evolve if companies and households make decisions which are least cost from a private perspective. (**Exhibit 18**). [15][16]

By comparing this private least cost scenario with the pathway required to achieve net zero emissions by 2050, we can therefore get a sense of where we have to go faster than will naturally occur if we want to limit global warming to well below 2°C. Three key points emerge from that comparison:

- First the private least cost route would entail almost no progress in reducing emissions in the heavy industry and long-distance transport sectors. (**Exhibit 19**); which is exactly what we would expect given that in these hard to electrify sectors there are likely to be significant green premia , certainly for several decades and in some cases forever. Only therefore if we impose carbon prices and regulations, and accept the small customer cost penalty, will we achieve the reductions in these emissions required for a well below 2°C limit.

- Second, BNEF project that in their least cost scenario, the decarbonisation of power generation will progress more slowly than required, with the share of clean electricity reaching 67% in 2035 and 75% in 2050 , versus the 89% and 100% required in a net zero scenario (**Exhibit 20**)

- Third, BNEF show that while electrification is an inevitable trend, driven by fundamental technological factors, under the least cost route , electricity's share of final energy demand would reach 25% in 2035 and 31% in 2050, versus the 33% and 51% shares required on a net zero scenario.

Now of course these are just projections ; and it is possible that BNEF are too cautious in their assumptions about the pace of cost decline in clean electricity technologies. Indeed it is important to recognise that that pace is to a degree endogenous to how fast

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[15] The BNEF NZ scenario shown on Exhibit 10 was produced in 2024, and was estimated to be compatible with a global warming limit of ~ 1.7°C (check) BNEF will be issuing a new net zero scenario in April 2026

[16] It is important to be precise in the use of the term " least cost" . The BNEF ETS scenario is clearly not least cost in an overall social sense, since it would entail a degree of global warming which would induce severe human welfare effects . It is thus a " private least cost" scenario before allowing for the cost of the climate externality , and in Lecture 1 I argued that ,once the adverse impact of climate change is allowed for, the socially optimal objective must be well below 2C
In addition to the climate externality , there may also be other adverse environmental effects (e.g local air pollution) which make BNEF ETS scenario not least cost from a social perspective.
Moreover it may be possible to deploy public policies (such as the use of government and MDB balance sheets) which , through reducing the cost of capital , enable a lower emission scenario to be achieved at no additional private cost . Finally , it is important to recognise that the future cost of different technologies is not an exogeneous given, but itself determined by the pace of deployment of clean technologies . Lecture 3 will consider the potential for such policies and effects . The BNEF ETS scenario should therefore be considered as "t*he private least cost scenario if one assumes broadly unchanged public policies, and without allowing for endogenously induced cost reduction."*.

we electrify and decarbonise: the faster we deploy the technologies, the faster costs are likely to fall.[17]

But it still remains likely that if we are to limit global warming to well below 2°C we will have to drive electrification and power decarbonisation faster than will occur simply as a result of the long-term superiority of the electrical tech technologies..

And going faster than the least cost route will entail two types of additional cost :

- The costs of initial subsidies
- And the costs of retiring legacy assets before end of useful life.

Initial subsidy costs

The learning curve and economy of scale effects which I described in Lecture 1 are powerful and after a time self reinforcing, but initial subsidies are often needed to unleash the dynamic

- Solar PV technological progress and cost reductions have progressed so far that its rapid spread across the world is unstoppable,: but that progress would not have been achieved so fast without huge initial subsidies for initially expensive solar PV deployment, in particular in Germany. Between 2000 and 2020 , total gross payments to support PV roll out in Germany amounted to around 100bn euros , and in 2020 the annual net subsidy (after deducting the wholesale price of electricity as an indicator of alternative supply costs) was around 10 bn euros per annum[18].

- In the UK, the initial deployment of onshore and offshore wind as well as solar was driven by a explicit subsidy system – the ROC regime - which in 2025 was adding about £7bn to the cost of the electricity system , of which about £3bn fell on household electricity bills – about £86 per annum per household[19][20] : from April 2026 , 75% of that cost will be transferred to public expenditure.

- And looking forward while some technologies in some regions – in particular solar PV in the global sunbelt – will increasingly require no subsidies, there are others, including probably the electrification of industrial heat, where rapid progress may well require some financial support.

[17] https://www.inet.ox.ac.uk/publications/modelling-induced-innovation-for-the-low-carbon-energy-transition-a-menu-of-options

[18] www.netztransparenz.de/xspproxy/api/staticfiles/ntp-relaunch/dokumente/erneuerbare%20energien%20und%20umlagen/eeg-jahresabrechnungen/vorjahre/eeg-jahresabrechnung_2020.pdf

[19] https://www.gov.uk/government/publications/renewables-obligation-level-calculations-2023-to-2024/calculating-the-level-of-the-renewables-obligation-for-2023-to-2024

[20] https://www.nesta.org.uk/project/finding-ways-to-deliver-cheaper-electricity-by-rebalancing-levies/household-energy-bills-green-levies

Legacy assets.

The faster we drive the transition to a zero carbon economy, the greater the extent to which we must retire assets before the end of useful life, and that can result in significant costs.

Legacy assets can arise in many sectors. For instance,

- Iron making blast furnaces can typically operate efficiently for 30 to 50 years after construction. Replacing them with alternative technology (such as H2 reduction based) at end of life may in any case impose a green cost premium: but that cost increases if carbon prices or other regulations are used to drive closure of blast furnaces before end of life. [21]Similar effects apply across the other heavy industry sectors

- And in countries which have large building heating requirements currently served by gas distribution networks, shifting to electric heating creates a transitional period in which expansion of electricity grids is adding cost, while the costs of operating gas distribution grids still largely remain. This effect may make it almost impossible to reduce total UK energy bills over the next 10 years, except by shifting some costs to the general government budget, even though in the long-term total energy bills will fall significantly

But it is in developing economy power sectors that the challenge of retiring existing capital assets is greatest, despite the fact that in the long run renewables will provide power at lower costs than fossil fuel fuels.

- Solar and wind are already the cheapest way to produce a kwh hour of electricity in most of the world: and renewables plus storage will increasingly outcompete new coal or gas as a way to produce round- the- clock electricity.
- But in some locations it could be many years before renewables plus storage can outcompete the <u>marginal</u> cost of running already existing coal and gas plants. And even if they can, many coal plants in developing countries have signed power purchase agreements which guarantee their revenues well into the future.
- Many existing coal plants will therefore run for many years and in some cases several decades unless someone is willing to pay the economic cost of closing them or at least running them at lower utilisation rates by shifting to a role as flexible back up to a renewable dominated system. Across the world ~810GW of new coal generating capacity has been added since 2014 (**Exhibit 21**)

[21] https://www.energy-transitions.org/publications/making-net-zero-steel-possible/

Estimates made by the ETC in 2023 illustrate the scale of the financial challenge [22] **(Exhibit 22**). If it cost two cents per kilowatt hour to incentivise the elimination of 4000TWH of coal generation currently producing 3.5GT of annual CO_2 emissions, that would cost $80 billion per annum for a significant number of years. Of this, the ETC estimated that $25-40bn would be required in middle and lower income countries outside China, tapering down over a 10 to 15 year period as assets naturally retire.

At the Glasgow COP 26 conference in 2021, the global strategy to reduce coal generation therefore combined three elements.

- A formal conference agreement to "accelerate efforts towards the phase down of unabated coal power"
- A "coalition of the willing" of 45 countries who committed to accelerate the phase out of unabated coal, with several setting targets for complete closure in the 2030s and 40s
- And the launch of the Just Energy Transition Partnership (JET-P) framework through which developed countries pledged $8.5bn to support South Africa with the transitional costs of phasing down coal: subsequent JET-P programs were agreed with Indonesia and Vietnam

But actual progress in reducing coal power has been minimal outside the developed countries.

In Lecture 1 I referred to the ETC's 2021 report on what needed to be achieved in the 2020s to "Keep 1.5°C alive".[23] The key actions included an end to deforestation and a significant growth in the volume of carbon removals, both of which would require someone to pay for a costly action, and neither of which have developed on anything like the scale required.

One other "Big Miss" of the 2020s has been the failure to make progress on closing down existing coal. (**Exhibit 23**) The ETC estimates that against an objective of reducing coal related emissions by 3.5GT p.a. by 2030 , none has been achieved.

Three of the four big misses of the 2020s, which have effectively put 1.5°C out of reach, are therefore not ones where fast technology progress alone can deliver emission reductions at the pace required: but ones where someone has to pay significant costs

Distributional effects between and within countries: jobs, costs and rents.

A third set of economic challenges arises from distributional effects. All processes of technological change create winners and losers, and if significant losses are not

[22] https://www.energy-transitions.org/publications/financing-the-transition-etc/
[23] https://www.energy-transitions.org/publications/keeping-1-5-alive/

anticipated and managed, political opposition will threaten the pace of the energy transition.

So it is important to assess at least three dimensions of distributional impact :

- First on employment: and here I will argue that it is important not to overstate the scale of the effect , whether positive or negative, while still focussing on specific concentrated problems and opportunities. -
- Second on costs to different countries , industries, of groups of individuals : and here I will focus in particular on an emerging inter-country effect which challenges past assumptions
- Third on economic rents, and in particular rents for fossil fuel production, and the implications for successful strategies to reduce fossil fuel consumption

Employment creation and destruction – less significant than often assumed

The energy transition will eliminate some existing jobs and create new ones , and many contributions to climate change policy debates stress how large is either the job threat or the opportunity. But I want to start with 5 caveats against overstating either the opportunities or the challenge.

First, in both developed and developing countries, most jobs will be unchanged by the nature of the energy used. In the UK for instance (**Exhibit 24**) the vast majority of workers are not involved in either the production of energy or of energy making equipment, but use energy, primarily in the form of electricity, in buildings primarily heated with gas. Switching from fossil fuel generated electricity to electricity derived from renewables, will have no impact on the number, the relative income, or the work activities of the vast majority of UK workers who work in education, health and local services, in public administration and defence, in finance and business services, in professional and scientific and managerial activities, in arts and entertainment , in hotels and restaurants. Nor will there be a change in transport and storage, since electrification per se – unlike autonomous driving – has no necessary impact on the number of taxi or lorry drivers; nor does the use of sustainable instead of conventional jet fuel, or ammonia instead of heavy marine oil , have any significant implications for the number of jobs in aviation and shipping .

Second , we should be clear that in the long run, a deeply electrified economy may employ fewer people in the energy producing sector, and in the production of energy using equipment, precisely because it will be a more efficient system, delivering energy services at lower cost to consumers. EVs are going to be cheaper to buy than ICEs because they have far fewer moving parts, and that means that automotive manufacturing will employ fewer people. Solar PV and battery costs have fallen faster than those for carbon capture and storage, precisely because these products are susceptible to the standardisation, economy of scale and learning curve effects which I described in Lecture 1. But that means that they need few workers to produce: visit a battery or solar PV manufacturing plant and you will see very few workers ,and the number per output volume is falling fast.(**Exhibit25**) .

Proponents of the energy transition can't have it both ways: we can't claim that the new energy system is lower cost to consumers and that it will create more jobs except to the extent that two effects are at work

- First that wages per job are lower than in today's system.
- Or second that consumers gain from the elimination of natural resource rents , even if the labour cost input to energy production rises

That latter effect will to a degree apply, but not to a sufficient degree to support the argument that in the long run the energy transition creates more jobs . It only applies to the energy production sector, not to the manufacture and servicing of energy using equipment. And if in the long run an electrified system is one which produces electricity at close to zero marginal cost, it is also by definition one which employs very few people.

Even in the period of initial investment the total employment effect is still relatively small . As **Exhibit 26** shows potential global employment in the manufacture , installation, operation and maintenance of wind and solar generation equipment which could grow from today's ~5m to around 20m by 2040 before declining thereafter. This will never be more than about 0.3% of the world's working age population.

Third, the job changes that we will face, either positive or negative, are an order of magnitude less than those which have resulted from past technological transitions, and far less important than other employment challenges likely to be faced in future. In 1900, most people even in the richest developed countries were directly or indirectly in agricultural: as late as 1950 30% of French workers and over 40% of Italian worked in food production related activities[24].[25] Today that percentage in all rich developed countries is less than 5% and in some cases below 2%[26]. In the UK in the 1920s, 6.5% of the workforce was engaged in coal mining, as late as 1950 still 3.3% , today none. { **Exhibit 27**) None of the employment impacts of the energy transition over the next 75 years will be remotely comparable with the seismic changes which we have seen as a result of technological change over the past 75 .

Fourth , in many developing countries, the impact of the energy transition on employment, whether negative or positive, will be trivial compared to the employment challenges created by demographic growth. India currently has about 400,000 coal miners and those jobs will be threatened by decarbonisation. But this is a drop in the ocean compared with India's overall job creation challenge. Out of a working age population of 800 million in 2019, only 460 million were identified as having any form of

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[24] https://www.cambridge.org/core/books/abs/growth-of-the-italian-economy-18201960/an-economic-miracle-italy-in-the-golden-age-1945196

[25] www.imf.org/-/media/files/publications/wp/2019/wpiea2019041.pdf

[26] In the UK the share is now 1.3% https://www.gov.uk/government/publications/farming-evidence-pack-a-high-level-overview-of-the-uk-agricultural-industry

employment, and out of that only 110 million had a regular wage and/or formal employment contract. (**Exhibit 28**)And while GDP grew by 58% between 2012 to 2019, and the working age population by 130m, identified formal employment grew just 2 million. India's challenge of rapid but jobless economic growth, is only trivially affected, for good or ill, by the energy transition.

Even more so in Africa, demographic driven growth in the working age population, potentially growing from 600m in 2022 to around 2bn by 2100, dwarfs any job creation potential from renewable power installation or other jobs directly created by the energy transition. (**Exhibit 29**)

Fifth and finally , technologically driven automation is already having far larger effects than the energy transition on employment and will likely do so even more in future. Chinese employment in coal mining and related activities has already fallen from 5.3 million in 2012 to around 2.5 million today, despite an increase in coal output from 3.7 to 4.8 bn tonnes . Similarly India's coal mining employment has fallen from 800,000 in 2010 to 400,000 today, even as output has remained stable. And if artificial intelligence and robotisation have even a small fraction of the productivity and employment consequences which are hoped for or feared, the employment consequences of the energy transition, whether positive or negative, will be little more than a footnote.

Specific focussed employment effects

But despite these caveats, there will still be important regional and sector employment effects which we need to anticipate, in order to both manage the negatives and maximise the positives.

Employment in automotive manufacture will fall worldwide because EVs are simpler products to produce with far fewer parts. The IEA estimates that there are around 11m workers directly employed in car manufacturing world wide [27]. But more are employed in the complex supply chains which support end product manufacture : research supported by the European Commission estimates about 2 million directly employed in Europe , and a total of 6 million once indirect links are considered[28] . These numbers will inevitably fall as result of increased automation and the switch to electric vehicles : but Europe's automotive employment could fall still faster if Europe's manufacturers not only transition to making EVs but also lose market share to Chinese imports. Ensuring that Europe and the UK maintain a major role in EV manufacturing is therefore vital.

Jobs will also be lost in the automotive service and repair business: the UK Climate Change Committee estimates that consumers could gain £7 billion per annum by 2050

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[27] https://www.iea.org/reports/what-next-for-the-global-car-industry/the-global-car-industry-in-context

[28] The Automotive Supply Chain in Europe: An Input-Output Analysis of Value Added and Employment Composition, European Commission Joint Research Centre www.econstor.eu/bitstream/10419/231347/1/jrc-wplet202101.pdf

because EVs will require far less maintenance than ICEs : but that must mean something like 100,000 fewer jobs in that sector

But conversely there is a major job creation opportunity in improving the insulation levels of the UK housing stock and installing heat pumps in place of gas boilers (**Exhibit 30**) Total jobs in these activities could expand to over 200,000 in the 2030s, tailing off only after 2045.

In the UK and across the world therefore, public policies should include a focus both on specific sectoral job challenges, and on making sure that new job creation opportunities are grasped as rapidly as possible.

But we should neither over sell the case for energy transition as a route to a green jobs bonanza, nor fear that huge scale job losses make the transition politically impossible.

Costs to consumers, industry, and countries .

If the job effects of the energy transition are sometimes overstated, differences in the future cost of energy supply and energy based services – both within and between countries - sometimes receives insufficient attention.

And in the case of intercountry differences, recent technology and cost trends have implications which challenge past assumptions.

Unequal effects on consumers : EVs , heat pumps and shipping

On average, within both developed and developing countries, most consumers will gain significantly from the switch to electric vehicles, electric heat pumps, more efficient air-conditioners and other electrical equipment. But it is vital to anticipate and manage specific distributional effects. (**Exhibit 31**)

- On average, consumers will benefit significantly from buying EVs rather than internal combustion engine vehicles, with lower operating costs and in future lower upfront purchase cost. But only "on average". In the UK, electricity costs for EV users who have off street parking and can therefore charge at domestic electricity rates, are about a third of those paid by people who have to charge on street or on highway. For the latter, which amount to around 35% of households, buying an EV is not currently an economic proposition. The importance of this adverse distributional effect will diminish over time as EVs become cheaper to buy upfront, and can be offset by changes in behaviour, with , for instance, an increasing share of young people living in major cities choosing not to own a car , but renting EVs when needed. But governments seeking to speed the transition to EV adoption should focus on ensuring widespread charging availability at as low cost as possible[29]

[29] Achieving this may require a greater role for strategic direction rather than relying on market competition : e.g by requiring local electricity distribution companies to build a specified density of on street charging, and enabling users to use these charging points to source electricity from their home electricity suppliers.

- And on average, homeowners will gain if they replace old gas boilers with new heat pumps. But only “on average” , both because the investment required will differ significantly between specific property circumstances, and because the effective marginal cost of capital differs dramatically by income group. For richer people, with spare cash in the bank, investing in a heat pump means foregoing an interest rate of 3 to 4%: for lower income capital constrained households, the effective marginal cost of capital reflects the 20% plus cost of credit card borrowing; and that can destroy the economic case for heat pump investment. Government support for the installation of heat pumps by lower income households will be essential to support rapid heating decarbonisation in many countries.

- Conversely, it is worth noting that some aspects of the energy transition will have trivial distributional effects. Decarbonisation of global shipping, potentially driven by carbon pricing and regulation of the sort which the International Maritime Organisation (IMO) has proposed, would gradually overtime result in a very significant increase in shipping freight rates : but the impact of these on consumer prices – e.g. the price of a pair of jeans made in Bangladesh and bought in London – will be so small that consumers will not notice, and will have a neutral distributional impact, with all consumers facing minimal cost increases broadly proportional to their total expenditure.

As discussed already in Lecture 1 long distance transport and heavy industry are “hard to electrify” sectors, but in terms of consumer impact, distributional effects and political sensitivity, residential heating is far more “hard to abate” .

Inter -country differences: the sunbelt versus the wind belt.

In most debates about fair emission reduction targets , there is assumption that high income countries must lead the way for 3 reasons:

- First because they have higher per capita emissions and therefore a responsibility to reduce their outsized impact on the global climate .
- Second because their higher income gives them greater technological capability to decarbonise at low cost.
- And third because unlike developing countries they do not face the challenge of combining decarbonisation with rapid growth in energy supply to support income catch up towards developed country levels.

The first rationale remains powerful and I will return to the issue of relative responsibilities in Lecture 3.

But the second rationale is challenged by the fact that it is China not the developed countries, which now leads in almost all clean technologies.

While the third is challenged by this exhibit (**Exhibit 32**) which I showed in Lecture 1 , which suggests that total system costs of round the clock electricity in renewable dominated power systems are likely to be significantly lower in the countries of the "global sunbelt" than in the high latitude "wind belt". This is for two reasons ;.

- First that solar PV costs have fallen faster than wind turbine costs, and are likely to continue to do so in future; so total costs fall faster in countries where solar is likely to be the major resource .
- Second because the system balancing cost will also be lower in sunbelt countries since ;
    - In sunbelt countries the main system balancing cost will be diurnal (keeping the air-conditioners running after the sun has gone down) - a balancing need which can primarily be met with ever cheaper batteries
    - While the biggest challenge in the high latitude wind belt is seasonal (keeping electric heating running during a 2 to 3 week wind drought produced by a winter anticyclone in the North Sea) - a balancing need which can only be met with more expensive technologies , such as hydrogen production and storage

Now of course, what Exhibit 32 presents are projections based on assumptions about future cost trends: and those assumptions could be wrong . But real world market prices suggest that the cost difference will be even bigger than Exhibit 32 suggests.

Exhibit 33 compares the results of the just completed AR7 auction for offshore wind in the UK, with those for a new "round the clock" (ROTC) renewable auction in India, with a headline UK strike price which is 2.5 times the Indian level. But the UK price is indexed to inflation throughout the 20 year contract , while the Indian price is fixed nominal, and in real terms will fall by around 50% during the period of the 25 year contract. And the UK price is for straightforward supply when the wind is blowing, and does not include any balancing cost; while the Indian result is for a "round the clock" contract which requires the winner to deliver electricity 75% of all hours, rising to 85% in three years time, and to themselves invest in the mix of renewable sources and storage mechanisms required to meet this commitment.

Effectively therefore, the UK wind belt cost is more like 4 to 5 times the Indian sunbelt cost than the 2.5 times differential in the headline strike price. This is real world, market price evidence of a huge sunbelt cost advantage in the supply of zero carbon power.

And it has profound implications both for economic development opportunities, and for international competitiveness.

- First,it implies that in many countries in the global sunbelt, including for instance the low income countries of sub-Saharan Africa, there will be no cost penalty but rather a huge low cost opportunity in developing power systems based primarily on renewable sources , rather than passing through a phase of fossil fuel based development. Though with one caveat: that seizing this potential rapidly will depend on the ability to fund development at a reasonable cost of capital ; **Exhibit 34** shows an estimate of the levelized cost of electricity from gas and from solar PV in 2020 and 2040 , for different African countries plus Yemen, which face different estimated real costs of capital . It suggests that by 2040 the upfront equipment cost of solar PV may be so cheap that solar will beat gas even at a very high 17% real cost of capital. But the more that the cost of capital can be reduced , the more rapid can be Africa's solar take off [30]

- Second, it means that countries across the global sunbelt, whether in the high income Gulf and Australia, middle income India, or low income countries in Africa, will enjoy a structural cost advantage in the production of zero carbon electricity, and therefore green hydrogen, and therefore key industrial products such as green ammonia/fertiliser, and green iron making. Indeed analysis by the Mission Possible Partnership, which systematically tracks the project pipeline of clean technology developments in the hard to electrify sectors, show that a significant skew towards more rapid development in the global sunbelt has already emerged . (**Exhibit 35**) [31]

- Third and conversely that means that heavy industry currently located in high latitude rich developed countries – whether Japan, Korea, Europe, or North America - is likely to face a structural cost disadvantage in the production of basic industry materials even if we achieve a world where high and common carbon prices eliminate the potential for unfair competition based on lower environmental standards.

This structural cost advantage, which has only become apparent (at least to me) in the last 3 to 5 years as clean tech cost reductions have gathered place, has important implications both for the fair distribution of emission reductions targets between different countries and for appropriate industrial strategies in developed countries, to both of which I will return in Lecture 3.

Economic rents ; transitioning beyond fossil fuels

I suggested earlier that threats to jobs, (as well as opportunities for jobs) are somewhat less important to the economics of the energy transition than sometimes assumed.

By contrast, threats to economic rents have a fundamental role in creating opposition to climate change action .

[30] https://files.wri.org/d8/s3fs-public/2023-08/path-across-the-rift-africa-energy-transitions-en.pdf

[31] https://ita.missionpossiblepartnership.org/news/entry/new-industrial-sunbelt-set-to-overtake-the-world-s-biggest-economies-in-clean-industry-race/

By far the most important of those economic rents – i.e. revenues in excess of fully loaded cost of production – arise from oil and gas and to a lesser extent coal[32]. The World Bank estimates that total rents from oil production run on average at around 1.5% of global GDP per annum, (**Exhibit 36**) and rents from gas production are also significant. Most of these rents accrue not to the international oil companies (IOCs) (i.e. the major private oil and gas companies of the developed world such as Exxon , Shell or TOTAL) , but to state owned National Oil Companies (NOCs) such as Saudi Aramco. And the revenues which result are seen as crucial to national economic development, public finances, and current account balance.

As a result, fossil fuel rents have a big influence on government climate related policies , and in particular on willingness to phase out fossil fuel.

- In some countries they create direct opposition to national and global climate change action. Lobbying by parts of the US fossil fuel industry has been a key driver in motivating Republican Party opposition to responsible climate change policy at national or global level. Saudi Arabia is nominally committed to global action on climate change and has a 2060 net zero target, but acts as a continued drag anchor on negotiations at COP and at the IMO.

- In other countries, fossil fuel rents undermine the extent to which top level commitment translates into actual emissions reductions. Opposition from Albertan companies and regional government are a major reason why Canada's NDC is rated as Almost Sufficient in terms of objectives but Highly Insufficient on policies and actions despite the personal belief of two prime ministers in a row – Justin Trudeau and Mark Carney – that climate change is a major global problem[33]. President Lula's leadership at COP 30 is combined with policies which seek to expand Petrobas production[34].

- And many developing countries – such as Guyana, Senegal, and Mozambique - are committed to developing new oil and gas production , and argue that the world has no right to deny them a share of global fossil fuel rents , simply because their reserves have been more recently discovered.

The net effect is that despite historic rhetorical commitment at the UAE COP 28 to "*transition away from fossil fuel*" we are facing what the IEA describes as a potential oil glut and Trafigura a " superglut" , along with large increases in LNG gas supply. (**Exhibit**

[32] The extent of economic rents is a function of the steepness of cost curves which show how the marginal cost of production increases as volume produced increases. Production cost curves for oil and gas are steeper than for coal, and as a result larger economic rents arise. See ETC *Fossil Fuels in Transition*, 2023. https://www.energy-transitions.org/publications/fossil-fuels-in-transition/

[33] https://climateactiontracker.org/countries/canada/2035-ndc/

[34] https://agencia.petrobras.com.br/en/w/petrobras-aprova-plano-de-neg%C3%B3cios-2026-2030

37) [35] [36]. Both of these supply expansions will help keep fuel fossil fuel prices low, slowing the progress of the energy transition.

For some commentators – such as Dan Yergin and his co-authors of the Foreign Affairs article which I mentioned in Lecture 1 - the glut is proof that the world needs more fossil fuels to support prosperity growth, and if that results in global warming of around 2.5° by the end of the century, we can and must adjust to that reality.

And for many countries and companies, even if they do believe we must limit global warming to well below 2°C, it provides justification for the argument that constraining their own specific supply will have no implications for global warming, since if they do not increase supply others will.

And in practice this latter group may well be right.

In theory there is no reason why supply constraints on fossil fuel production should not play a major role in driving the energy transition. Indeed in a rational world, in which a rational global government accepted the advice of a rational economist – a market friendly global supply constraint could be a perfect policy.

- If we worked out the maximum amount of coal, oil and gas which we could still use while staying within an agreed temperature limit, and auctioned rights to produce that quantity and no more to the highest bidders, that would generate prices for fossil fuels which would drive a least cost transition to a newly electrified economy at precisely the required pace.

- The same effect could also be produced if there were above us a benevolent deity, and if she were to send angels in the night to steal most of our fossil fuels leaving us only with the amount which we can safely burn while still limiting global warming to well below 2C. .

But in the real world, the chances of either occurring are nil.

And in the real world, I therefore do not think we should expect voluntary unilateral or "coalition of the willing" commitments to constrain fossil fuel supply to play a major role in achieving our climate change objectives. In some cases they can provide useful signalling to investors about the direction of change.. But the heavy lifting will have to be done by actions which drive down demand for fossil fuels, and which thereby convince potential investors that further investment in fossil fuels will be uneconomic.

That means installing renewables or nuclear fast enough to reduce demand for coal and gas: electrifying road transport to reduce the demand for oil; electrifying residential heat and reducing gas demand; and applying carbon prices in the hard to electrify

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[35] https://www.iea.org/commentaries/as-oil-market-surplus-keeps-rising-something-s-got-to-give

[36] https://oilprice.com/Energy/Energy-General/Trafigura-Warns-of-Super-Glut-as-Oil-Supply-Surges.html

sectors to reduce the demand for gas in high temperature heat generation, coking coal in iron reduction or heavy fuel oil in shipping.

Economic rents mean that if we want to transition beyond fossil fuels we have to reduce demand for them.

China ; the challenge and opportunity

Finally in today's lecture , I will focus on China, because what China does and how the rest of the world responds to China will be absolutely crucial to whether we can keep global warming well below 2°C.

Two stories are told about China and climate change.

- The first is that China is the biggest greenhouse gas emitter, and that it's formal commitments to reduce emissions reductions are incompatible with a global temperature limit of well below 2°C let alone 1.5°.
- The second is that China is a leading the world in the development and deployment of the technologies which the world needs to achieve a well below 2° limit.

Both stories are true ; and relationship between China and the rest of the world, and in particular China and Europe, must start with honest recognition of both realities.

China's current annual GHG emissions of 15GT are now about 30% of the global total , as against 3.5GT for the whole of Europe and the UK together, and about 4GT for India. (**Exhibit 38)** And its per capita emissions have overtaken those of Europe and the UK, and on the basis of current declared plans, will be over twice as high by 2035.

Looking forward, **Exhibit 39** presents estimates of what total cumulative future emissions might be for different countries or groups of countries if they deliver the pledges they have made, including both NDC targets for emission reductions over the next 10 years and commitments to reach net zero by a specific date. In the US case, there is regrettably now no pledge to reduce emissions at all, and while on the previous pledge the US total might have been about 70 Gt, it may now be significantly higher.

But if China meets both its 2035 NDC commitment, and its net zero by 2060 goal, its cumulative emissions could amount to about 260 GT , while Europe and the UK together are on target for cumulative emissions of around 25 Gt, reaching zero in 2050.

The blunt reality is that with the US refusing to play any responsible role in dealing with this huge global problem, future global temperatures will be determined by decisions made in Beijing, and to some extent Delhi, far more for than in Brussels or London.

China's now very high per capita emissions reflect two key factors

- First an electricity system which, despite massive investment in renewables, hydro and nuclear generation, is still dominated by coal generation, and as a result produces electricity with an average carbon intensity far above European , US or UK levels (**Exhibit 40)**. How rapidly China reduces coal generation will be a key driver of future global temperatures.

- Second very large emissions from heavy industry, and in particular from cement and iron and steel production. China accounts for just over 50% of global steel production and cement production, and a similar share of global emissions from those sectors. These dominant shares reflect the huge role that construction has played in the Chinese economy, and the more recent growth of steel exports as domestic construction activity has begun to decline[37][38] .In the case of steel it also reflects the limited current role for recycled steel and the dominance of primary iron production. (**Exhibit 41**)

Petrochemical, ammonia and aluminium sectors are also significant emitters.

China must therefore play a central role in any credible strategy to decarbonise the hard to electrify sectors of the global economy. It is already doing so in the development of the relevant technologies, with several companies developing H2 DRI iron production technologies, major progress in reducing the cost of electrolysers and green H2 production, large scale green ammonia developments, and large scale deployment of new cement chemistries which significantly reduce clinker content and therefore CO2 emissions . But it will need to combine technological development with domestic carbon pricing or equivalent regulation if it is to drive emissions reduction at the pace required.

China is already of course by far the global leader in the development and deployment of the clean electrical technologies which I described in Lecture 1

- Global solar PV installations have soared far above past projections – but over 50% of those installations are in China. (**Exhibit 42**)
- On average wind turbine costs have fallen significantly over the last 5 years , but only because of dramatic falls in China : buyers of non-Chinese wind turbines have seen no reduction (E**xhibit 43**)
- Battery cost reductions have been driven primarily by Chinese companies, and China accounts for over 60% of global EV sales .
- China is already seeing a significant rise in electricity as a share of total energy use, while Europe the US and many other countries lag behind. (**Exhibit 44**)
- And if we look at global manufacturing capacity in multiple technologies which will be central to achieving massive clean electrification, China accounts for huge shares, and shares which have actually increased since 2022 (**Exhibit 45**)

[37] https://www.energy-transitions.org/publications/china-2050-a-fully-developed-rich-zero-carbon-economy/

[38] https://www.energy-transitions.org/publications/achieving-a-green-recovery-for-china/

It is important to be clear about the roots of this technological and cost leadership. They are sometimes assumed to be low-cost labour, lower environmental standards, and direct current state subsidies – and some of these elements did play a role at an earlier stage of development. But increasingly China's advantage is based on more fundamental factors which become self reinforcing over time and are likely to be permanent.

These include;

- Excellence in science and technology – with a massive supply of highly skilled scientific researchers and of engineers who can to turn scientific insight into low cost products manufactured in super efficient factories . CATL , the largest Chinese battery manufacturer has ~20000 people working in its research and development department : while BYD , which produces everything in a vertically integrated chain from EVs of all types to multiple battery chemistries, is reported to have ~110,000 working in research and engineering roles[39][40]. In total China has about 4 million graduates is STEM disciplines per annum versus about 800,000 in the US[41]
- A strategic commitment to the massive scale deployment of the key technologies, which unleashes economy of scale and learning curve effects, not only in end products – EVs , solar panels, wind turbines or electrolysers – but in every step of their supply chains
- The mutually reinforcing nature of leadership in each element of their electro-tech stack which I described in Lecture 1 (**Exhibit 46**)
- And finally a low cost of capital, rooted in structurally high corporate and personal savings rates, and in features of the Chinese financial system and regulation. Not surprisingly, when it comes to leadership in technologies characterised by high upfront costs and low or zero marginal costs, a country with a lower cost of capital has a significant advantage.

In a world of complete peace, geopolitical cooperation, unperturbed by of economic stress, what China has done to develop and deploy clean technologies would be lauded as a huge contribution to solving global warming . And let me be clear –we should respect and praise China for that contribution. Because of what China has achieved, the whole world can now progress more rapidly and more cheaply towards a zero carbon electrified economy than previously seemed possible.

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[39] https://carnewschina.com/2024/12/30/byd-has-the-most-rd-personnel-as-an-automaker-and-nearly-110000-engineers-ceo-says/

[40] https://www.essdaily.com/china/catls-2024-financial-report-revenue-declines-while-net-profit-rises

[41] https://cset.georgetown.edu/article/the-global-distribution-of-stem-graduates-which-countries-lead-the-way/

But in the real world of geopolitical tensions and economic challenges, China's leadership also creates concerns – about industrial competitiveness and jobs, and about security.

And those issues are particularly pressing in Europe, which faces a perfect storm of threats to its industrial competitiveness and to its capacity to respond to them. (**Exhibit 47)** –

- Ten or even five years ago, the threats appeared focused simply on carbon intensive heavy industry, and a sufficient response seemed clear. Europe had implemented an Emissions Trading Scheme to drive the decarbonisation of heavy industry ; that would obviously create a competitiveness problem if other countries did not commit to equivalent carbon prices: but the sufficient policy response seemed obvious – a carbon border carbon adjustment, the CBAM. And as I will argue in Lecture 3 that remains an appropriate policy which Europe and the UK must implement in a robust and unapologetic fashion. But increasingly it is clear that even with a common carbon price across the world, European heavy industry may not be competitive with a global sunbelt which enjoys a structural advantage in the production of clean electricity.

- Putin's invasion of Ukraine, meanwhile, produced a severe energy price shock to European industry and has necessitated significant increases in defence expenditure, which must to a degree compete with domestic energy transition support

- Europe is also buffeted by Trump's tariffs, both directly as they apply to Europe's exports to the US, and indirectly because falling Chinese exports to the US have been offset by rising exports to Europe

- And China's dominance of all the key technologies of the energy transition threatens Europe's hope that investments in clean industry could be a key driver of European growth. Europe no longer has any serious solar PV manufacturing capability: in wind turbines, its costs are far above Chinese levels: in batteries, it has been unable to develop domestic companies which can compete with Chinese or Korean manufacturers, and both BritishVolt and NorthVolt have failed: European electrolyser manufacturers fear being overwhelmed by Chinese competition: and Stegra , formally H2 Green steel, is in the throes of a difficult financial restructuring. Europe's automotive industry, fears large scale job losses both because it is rapidly losing its Chinese export markets and because Chinese EV imports are super competitive in both quality and cost

How Europe (including the UK) should respond to these challenges is therefore a crucial question : and developing countries too will need to design policies which balance the imperative to keep clean investment costs as low as possible versus the desire to grow local employment and value added in clean technologies. I will propose key features of these policies in Lecture 3

One key question within those policies is the appropriate role of Chinese investment in other countries, an issue which relates also to China's role in "climate finance" .

As mentioned earlier, the global sunbelt sits on a huge opportunity to develop low-cost green power and green industry. But in some lower income countries the ability to seize that opportunity is impaired by a high cost of capital. And across many developing countries apart from India , investment levels for far short of those required (**Exhibit 48**).

Numerous reports have therefore discussed the need to mobilise international "climate finance" both for mitigation but for adaptation, and covering both the role of development banks in mobilising debt and equity finance , and the need for some direct grant finance support.[42][43] And debates over the scale of "climate finance" commitments have been central to negotiations at several COPs

Until now , these debates have been framed primarily in terms of the support which the developed world must give to the developing, with flows from China to developing economies see as secondary and covered under the rather quaint term of " south - south " cooperation.

But it is inevitable that China will play a very major and probably the dominant role in climate finance flows. (**Exhibit 49**) Net capital flows are by definition the inverse of net current account balances, and China's huge current account surplus, now running at ~$700bn per annum, must in some way be matched by Chinese capital investment in other countries.

And China already makes huge external investments , often in ways that create demand for Chinese clean tech equipment.

Approaches to climate finance mobilisation must therefore recognise the reality of China 's central rather than secondary role.

Summing up

So let me sum up (**Exhibit 50**)

In Lecture one last week. I hope I left those of you who were there feeling quite optimistic , because I described the technologies which could enable us to limit global warming to well below 2°C

[42]The G20 independent expert group report on strengthening multilateral development bank www.cgdev.org/sites/default/files/2024-10/IEG-report-triple-agenda-report-card-oct2024.pdf

[43] Independent high level expert group (IHLEG) for climate action https://www.lse.ac.uk/granthaminstitute/publication/finance-for-climate-action-scaling-up-investment-for-climate-and-development/

But tonight, I may have depressed you a bit, because I have a described multiple economic challenges which can slow progress, quite apart from the more purely political challenges with which I started this lecture.

But despite these challenges I believe there is a strategy which can still limit global warming to well below 2°C, as long as we recognise the implications of the challenges on this exhibit and design policies to respond to them.

Next Monday I will describe that strategy , and I hope some of you who are maybe feeling a bit depressed this evening, will come back to be cheered up next week.